

A METHOD AND APPPARATUS FOR SETTING A GUARD INTERVAL IN AN  
OFDM COMMUNICATION

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herein in its entirety.

5

BACKGROUND OF THE INVENTION

Field of the invention

The present invention relates to a  
10 transmission/reception apparatus used for digital mobile  
communications using an orthogonal frequency division  
multiplexing (hereinafter referred to as "OFDM") system.

Description of the Related Art

15 A Conventional OFDM transmission/reception apparatus  
is explained using FIG.1 and FIG. 2. FIG. 1 is a block  
diagram showing an outlined configuration of a transmission  
system of a conventional OFDM transmission/reception  
apparatus. FIG. 2 is a block diagram showing an outlined  
20 configuration of a reception system of the conventional  
OFDM transmission/reception apparatus.

In FIG. 1, serial-parallel converter (hereinafter  
referred to as "S/ P converter") 11 converts a serial input  
25 signal to a plurality of parallel signals. IDFT circuit 12  
performs inverse discrete Fourier transform (hereinafter  
referred to as "IDFT") on the input signals. Guard  
interval inserter 13 inserts a guard interval for every  
valid symbol. D/A converter 14 performs D/A conversion on  
30 the signal with guard interval inserted.

In FIG.2, A/D converter 15 performs A/D conversion on a reception signal. Delayer 16 delays the input signal by a valid symbol length. Correlator 17 despreads the input signal. Timing generator 18 detects the timing of the reception signal at which the correlation result becomes largest. Guard interval eliminator 19 eliminates a guard interval inserted for every symbol. DFT circuit 20 performs discrete Fourier transform (hereinafter referred to as "DFT") on the input signal. Coherent detectors 21 to 24 perform coherent detection on the input signal. Deciders 25 to 28 judge the input signal. Parallel-serial converter (hereinafter referred to as "P/S converter") 29 converts a plurality of parallel signals to a serial signal.

Then, the operation of the conventional OFDM transmission/reception apparatus is explained. Here, suppose the number of carriers is 4, for example.

First, the operation of the transmission system is explained using FIG.1. A modulated signal input to the transmission system is S/P-converted by S/P converter 11. This results in four modulated signals, which are transmitted by a first, second, third and fourth carriers, respectively.

Then, the 4 modulated signals are IDFT-processed by IDFT circuit 12.

A general OFDM transmission/reception apparatus has a frame format as shown in the frame format schematic diagram in FIG.3. That is, in a frame format used for

a general OFDM transmission/reception apparatus, a signal with the same waveform as that of the last part of a valid symbol is added at the start of the valid symbol as a guard interval. The OFDM transmission/reception  
5 apparatus can eliminate a delayed signal with a shorter delay time than this guard interval through DFT processing of the reception system.

Guard interval inserter 13 inserts a guard interval into the IDFT-processed signal. The signal with the  
10 guard interval inserted is converted to an analog signal by D/A converter 14. In this way, a transmission signal is obtained.

Then, the operation of the reception system is explained using FIG.2. The reception signal input to the  
15 reception system is converted to a digital signal by A/D converter 15.

Generally, the OFDM transmission/reception apparatus finds a correlation between a pre-DFT signal and the pre-DFT signal delayed by a valid symbol length.  
20 Then, the OFDM transmission/reception apparatus detects a DFT integration interval by detecting the timing at which the correlation result becomes largest. To be more specific, delayer 16 delays the reception signal by a valid symbol length, then correlator 17 finds a  
25 correlation and timing generator 18 detects the timing at which the correlation result becomes largest. Guard interval eliminator 19 eliminates the guard interval from the reception signal according to this detection

result.

The reception signal stripped of the guard interval is DFT-processed by DFT circuit 20. This results in 4 baseband signals, which are carried by 4 carriers. The 4 baseband signals are each subjected to coherent detection by coherent detectors 21 to 24. In this way, coherent detected signals are obtained.

Here, coherent detectors 21 to 24 are explained using FIG.4. FIG.4 is a block diagram showing an outlined configuration of the coherent detector of the OFDM transmission/reception apparatus. Digital multipliers 41 and 42 multiply the DFT-processed signals by pilot symbols. Conjugate complex number generator 43 generates a conjugate complex number for the input signal.

In a general frame format, a pilot symbol, a known reference signal, is added before a message interval. In a general coherent detection method, a fading variation is detected using a pilot symbol.

In  $(nT)$  which is a DFT-processed input signal in a pilot symbol interval is expressed as  $In(nT) = P(nT) \cdot A(nT) \cdot \exp(j\Theta(nT))$ , where  $P(nT)$  is a pilot symbol,  $A(nT)$  is an amplitude variation due to fading and  $\exp(j\Theta(nT))$  is a phase variation due to fading.

$F(nT)$ , which represents a variation due to fading, is expressed as follows:

$$F(nT) = In(nT) \cdot P(nT)$$

$$\begin{aligned}
 &= \{P(nT) \cdot A(nT) \cdot \exp(j\Theta(nT))\} \cdot P(nT) \\
 &= P(nT)^2 \cdot A(nT) \cdot \exp(j\Theta(nT)) \quad \text{---(1)}
 \end{aligned}$$

Here, in a modulation system such as a QPSK modulation system in which the amplitude is constant and only the phase contains information,  $P(nT)^2 = 1$ . Therefore, expression ① is expressed as follows:

$$F(nT) = A(nT) \cdot \exp(j\Theta(nT))$$

Then, digital multiplier 41 obtains signal  $F(nT)$  that represents a variation due to fading by multiplying DFT-processed input signal (baseband signal)  $In(nT)$  by pilot symbol  $P(nT)$  in a pilot symbol interval.

Then, conjugate complex number generator 43 generates a conjugate complex number about  $F(nT)$ , a signal representing a variation due to fading. In this way, conjugate complex number  $F(nT)^*$  of  $F(nT)$  signal expressing a variation due to fading is obtained. Conjugate complex number generator 43 inverts the polarity of the Q component of the input signal and generates a conjugate complex number. Therefore, conjugate complex number  $F(nT)^*$  is expressed in the following expression:

$$F(nT)^* = A(nT) \cdot \exp(-j\Theta(nT))$$

Then, digital multiplier 42 multiplies the DFT-processed input signal (baseband signal) by the conjugate complex number of the signal representing a variation due to fading. In this way, a coherent detected signal is obtained.

Here, suppose the fading variation is

sufficiently slow compared to the interval of pilot symbols and the fading variation is constant between pilot symbols. Based on this supposition, coherent detected signal  $D_{out}(nT)$  is expressed in the following expression:

$$\begin{aligned} D_{out}(nT) &= D_{in}(nT) \cdot A(nT) \cdot \exp(j\Theta(nT)) \\ &\quad \cdot A(nT) \cdot \exp(-j\Theta(nT)) \\ &= D_{in}(nT) \cdot A(nT)^2 \quad -\textcircled{2} \end{aligned}$$

In expression ②,  $A(nT)^2$  is the component with a constant phase and variable amplitude. Therefore, the phase variation of coherent detected signal  $D_{out}(nT)$  is only dependent on  $D_{in}(nT)$ . Therefore, the phase of the reception signal is demodulated by digital multiplier 42 multiplying the DFT-processed input signal (baseband signal) by a conjugate complex number of the signal indicating a variation due to fading. The QPSK modulation system is a modulation system with a constant amplitude and variable phase. Therefore, the OFDM transmission/reception apparatus performs coherent detection by demodulating the phase of the reception signal.

Furthermore, the OFDM transmission/reception apparatus can also eliminate any phase difference between transmission and reception carriers and phase variation by frequency offset as well as fading variation.

In a modulation system such as a 16QAM modulation

system with a variable phase and variable amplitude, the OFDM transmission/reception apparatus detects a fading variation by dividing an input signal in the pilot symbol interval by a pilot symbol. The OFDM transmission/reception apparatus then performs coherent detection by dividing the input signal by a signal indicating a fading variation.

The OFDM transmission/reception apparatus can also use a delay detection system as the demodulation system.

The coherent signals detected by coherent detectors 21 to 24 are judged by Deciders 25 to 28. After judgment, the 4 signals are converted to a single signal by P/S converter 29. In this way, a demodulated signal is obtained.

As shown above, the conventional OFDM transmission/reception apparatus adds a signal with the same waveform as that of the last part of a valid symbol at the start of the valid symbol as a guard interval. By providing the guard interval, the OFDM transmission/reception apparatus can eliminate a delayed signal whose delay time is shorter than the guard interval through DFT processing of the reception system.

The explanation above referred to a case where the number of carriers is 4, but the same apparatus configuration can also be used when the number of carriers is increased to 8, 16, 32, 64, and so on.

However, the conventional OFDM transmission/reception apparatus adds a guard interval

with a fixed length for every valid symbol independently of the channel quality. Therefore, in the case that the channel quality is good and the delay time of the delayed signal is short, a guard interval that is longer than  
5 necessary is added, which deteriorates the transmission efficiency.

#### SUMMARY OF THE INVENTION

10 It is an objective of the present invention to provide an OFDM transmission/reception apparatus capable of improving the transmission efficiency while maintaining the function of adding a guard interval to eliminate a delayed signal.

15 In order to achieve the objective above, the OFDM transmission/reception apparatus of the present invention changes the length of a guard interval added at the start of a valid symbol suitably to maintain the minimum necessary length of the guard interval (that is,  
20 the guard interval of an appropriate length) to eliminate a delayed signal at a given moment and in a given environment.

#### BRIEF DESCRIPTION OF THE DRAWINGS

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The above and other objects and features of the invention will appear more fully hereinafter from a consideration of the following description taken in



connection with the accompanying drawing wherein one example is illustrated by way of example, in which;

FIG.1 is a block diagram showing an outlined configuration of a transmission system of a conventional OFDM transmission/reception apparatus;

FIG.2 is a block diagram showing an outlined configuration of a reception system of the conventional OFDM transmission/reception apparatus;

FIG.3 is a schematic diagram of a frame format in an OFDM-based radio communication;

FIG.4 is a block diagram showing an outlined configuration of a coherent detector of an OFDM transmission/reception apparatus;

FIG.5 is a block diagram showing an outlined configuration of an OFDM transmission/reception apparatus according to Embodiment 1 of the present invention;

FIG.6 is a block diagram showing an outlined configuration of a guard interval inserter of the OFDM transmission/reception apparatus according to Embodiment 1;

FIG.7 is a timing chart showing an example of the step of a guard interval inserter of the OFDM transmission/reception apparatus according to Embodiment 1 adding a guard interval;

FIG.8 is a block diagram showing an outlined configuration of an optimal guard interval length detector of the OFDM transmission/reception apparatus

according to Embodiment 1;

FIG.9 is a block diagram showing an outlined configuration of an optimal guard interval length detector of an OFDM transmission/reception apparatus according to Embodiment 2 of the present invention;

FIG.10 is a block diagram showing an outlined configuration of an optimal guard interval length detector of an OFDM transmission/reception apparatus according to Embodiment 3 of the present invention;

FIG.11 is a block diagram showing an outlined configuration of an OFDM transmission/reception apparatus according to Embodiment 4 of the present invention;

FIG.12 is a block diagram showing an outlined configuration of an optimal guard interval length detector of the OFDM transmission/reception apparatus according to Embodiment 4;

FIG.13 is a block diagram showing an outlined configuration of an OFDM transmission/reception apparatus according to Embodiment 5 of the present invention;

FIG.14 is a graph showing a theoretical calculation result of an envelope information calculation approximate expression used in a level detector of an OFDM transmission/reception apparatus according to Embodiment 6 of the present invention;

FIG.15 is a block diagram showing an outlined configuration of a level detector of the OFDM

transmission/reception apparatus according to  
Embodiment 6;

FIG.16 is a block diagram showing an outlined  
configuration of an OFDM transmission/reception  
5 apparatus according to Embodiment 7 of the present  
invention;

FIG.17 is a block diagram showing an outlined  
configuration of an optimal guard interval length  
detector of an OFDM transmission/reception apparatus  
10 according to Embodiment 8 of the present invention;

FIG.18 is a block diagram showing an outlined  
configuration of an optimal guard interval length  
detector of an OFDM transmission/reception apparatus  
according to Embodiment 9 of the present invention;

15 FIG.19 is a block diagram showing an outlined  
configuration of an OFDM transmission/reception  
apparatus according to Embodiment 10 of the present  
invention;

FIG.20 is a block diagram showing an outlined  
20 configuration of an OFDM transmission/reception  
apparatus according to Embodiment 11 of the present  
invention;

FIG.21 is a block diagram showing an outlined  
configuration of an OFDM transmission/reception  
25 apparatus according to Embodiment 12 of the present  
invention;

FIG.22 is a block diagram showing an outlined  
configuration of an OFDM transmission/reception

apparatus according to Embodiment 13 of the present invention;

FIG.23 is a block diagram showing an outlined configuration of a UW detector of the OFDM

5 transmission/reception apparatus according to Embodiment 13 of the present invention;

FIG.24 is a block diagram showing an outlined configuration of a UW detector of an OFDM transmission/reception apparatus according to

10 Embodiment 14 of the present invention;

FIG.25 is a block diagram showing an outlined configuration of an OFDM transmission/reception apparatus according to Embodiment 15 of the present invention;

15 FIG.26 is a block diagram showing an outlined configuration of a UW detector of the OFDM transmission/reception apparatus according to Embodiment 15 of the present invention;

FIG.27 is a block diagram showing an outlined configuration of an OFDM transmission/reception apparatus according to Embodiment 16 of the present invention;

FIG.28 is a block diagram showing an outlined configuration of a UW detector of the OFDM transmission/reception apparatus according to Embodiment 16 of the present invention;

FIG.29 is a block diagram showing an outlined configuration of a UW detector of an OFDM

transmission/reception apparatus according to  
Embodiment 17 of the present invention;

FIG.30 is a block diagram showing an outlined  
configuration of an OFDM transmission/reception  
5 apparatus according to Embodiment 18 of the present  
invention;

FIG.31 is a timing chart showing an example of the  
step of a guard interval inserter of the OFDM  
transmission/reception apparatus according to  
10 Embodiment 18 of the present invention adding a guard  
interval; and

FIG.32 is a timing chart showing an example of the  
step of a guard interval eliminator of the OFDM  
transmission/reception apparatus according to  
15 Embodiment 18 of the present invention eliminating a  
guard interval.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

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With reference now to the attached drawings, the  
embodiments of the present invention are explained in  
detail below.

25 (Embodiment 1)

The OFDM transmission/reception apparatus  
according to Embodiment 1 of the present invention is  
explained using FIG.5. FIG.5 is a block diagram showing

an outlined configuration of the OFDM transmission/reception apparatus according to Embodiment 1 of the present invention.

S/P converter 101 converts a serial input signal to a plurality of parallel signals. Switches 102 and 103 switch between two input signals and outputs either of the two. IDFT circuit 104 performs IDFT processing on the input signals. Guard interval inserter 105 inserts a guard interval into the input signal for every valid symbol. D/A converter 106 performs D/A conversion on the signal with a guard interval inserted. In this way, a transmission signal is obtained.

A/D converter 107 performs A/D conversion on a reception signal. Delayer 108 delays the input signal by a valid symbol length. Correlator 109 despreads the input signal. Timing generator 110 detects the timing of the reception signal at which the correlation value becomes largest. Guard interval eliminator 111 eliminates the guard interval inserted for every valid symbol. DFT circuit 112 performs DFT processing on the input signal.

Coherent detectors 113 to 116 perform coherent detection on the input signal. Deciders 117 to 120 judge the input signals. Switch 121 selects a control signal to select the optimal guard length from the signal output from Decider 120. Subtractor 122 performs a subtraction between the signal input to Decider 117 and the signal output from Decider 117. Optimal guard interval length

detector 123 generates a control signal to select the optimal guard interval length from the output of subtractor 122. P/S converter 124 converts a plurality of parallel input signals to a serial signal.

5        Then, the operation of the OFDM transmission/reception apparatus according to the present embodiment is explained. Here, a case where the number of carriers is 4 is explained, for example.

First, the operation of the transmission system is explained. The OFDM transmission/reception apparatus of the present embodiment adds a signal to detect an optimal guard interval length (hereinafter referred to as "optimal guard interval length detection signal") to a carrier (here, a first carrier, for example) and adds  
10 a control signal to select an optimal guard interval length (hereinafter referred to as "optimal guard interval length selection control signal") to a carrier (here, a fourth carrier, for example). The OFDM transmission/reception apparatus of the present  
15 embodiment can also add an optimal guard interval length detection signal and optimal guard interval length selection control signal to a same carrier.

A plurality of symbols contained in the optimal guard interval length detection signal indicates  
25 different guard interval lengths. Here, suppose a symbol period consists of 8 symbols and an optimal guard interval length detection signal consists of 4 symbols. Therefore, in the case that the decision error of the

first symbol is large, the first symbol of the optimal guard interval length detection signal indicates that a guard interval length of "symbol period/2" is required. Likewise, the second symbol indicates that a guard  
 5 interval length of " $3 \times \text{symbol period}/4$ " is required; third symbol, a guard interval length of "symbol period/8"; and fourth symbol, a guard interval lengths of "symbol period/8."

A demodulated signal input to the transmission  
 10 system is S/P-converted by S/P converter 101. This results in 4 demodulated signals, which are transmitted by a first carrier, second carrier, third carrier and fourth carrier, respectively.

Switch 102 switches between the demodulated signal  
 15 transmitted by the first carrier and the optimal guard interval length detection signal and outputs either one to IDFT circuit 104. Furthermore switch 103 switches between the demodulated signal transmitted by the fourth carrier and the optimal guard interval length selection  
 20 control signal and outputs either one to IDFT circuit 104.

IDFT circuit 104 performs IDFT processing on the modulated signals output from S/P converter 101, which are transmitted by the second and third carrier.  
 25 Furthermore, IDFT circuit 104 performs IDFT processing on the signals output from switches 102 and 103.

Then, guard interval inserter 105 adds a guard interval into the IDFT-processed signal. An OFDM



transmission/reception apparatus generally uses a frame format as shown in the frame format schematic diagram in FIG.3. That is, in the frame format generally used in an OFDM transmission/reception apparatus, the signal  
 5 having the same waveform as that at the last part of a valid symbol is added at the start of the valid symbol as a guard interval. The OFDM transmission/reception apparatus can eliminate a delayed signal whose delay time is shorter than the length of this guard interval through  
 10 DFT processing of the reception system.

The signal with a guard interval added is converted to an analog signal by D/A converter 106 and becomes a transmission signal.

Here, guard interval inserter 105 is explained  
 15 using FIG.6. FIG.6 is a block diagram showing an outlined configuration of the guard interval inserter of the OFDM transmission/reception apparatus of the present embodiment.

S/P converter 201 performs S/P conversion on the  
 20 optimal guard interval length selection control signal, which is the output of Decider 120. Switches 202 to 204 switch between two input signals and outputs either one. Logical product calculator 205 performs a logical product calculation of the two input signals. P/S  
 25 converter 206 converts a plurality of parallel input signals to a serial signal.

The optimal guard interval length selection control signal is split into three control signals for

switches 202, 203 and 204 by S/P converter 201.

To switch 202, window signal 1 with a high-level interval of "symbol period/2" and window signal 2 with a high-level interval of " $3 \times$  symbol period/8" are input.

5 On the other hand, to switch 203, the output signal of switch 202 and window signal 3 with a high-level interval of "symbol period/4" are input. To switch 204, the output signal of switch 203 and window signal 4 with a high-level interval of "symbol period/8" are input. In  
10 this way, the number of window signals is the same as the number of symbols of the optimal guard interval length detection signal.

Then, switches 202 to 204 select window signals as shown in the table below.

Control signal to switch 202	Control signal to switch 203	Control signal to switch 204	Output of switch 204 (window signal selected)
0	0	0	Window signal 1 [symbol period/2]
1	0	0	Window signal 2 [ $3 \times$ symbol period/8]
1	1	0	Window signal 3 [symbol period/4]
1	1	1	Window signal 4 [symbol period/8]

15 As shown above, the OFDM transmission/reception apparatus of the present embodiment selects window signals using the decision error of each symbol of the optimal guard interval length detection signal. Then, the OFDM transmission/reception apparatus of the present  
20 embodiment can decide the guard interval length by calculating a logical product of the selected window signal (output of switch 204) and a valid symbol.

Logical product calculator 205 calculates the

logical product of the output of switch 204 and the output of IDFT circuit 104. In this way, the OFDM transmission/reception apparatus of the present embodiment can extract part of a valid symbol, and thus  
 5 can generate a guard interval.

Then, P/S converter 206 performs P/S conversion of the guard interval signal, which is the output of logical product calculator 205, and the output signal of IDFT circuit 104. In this way, an IDFT signal with a guard  
 10 interval inserted is obtained.

Here, the step of guard interval inserter 105 generating guard intervals is explained using FIG.7. FIG.7 is a timing chart showing an example of the step of the guard interval inserter of the OFDM  
 15 transmission/reception apparatus of the present embodiment generating guard intervals.

The signal shown at A represents a valid symbol. Likewise, B represents window signal 1; C, window signal 2; D, window signal 3; E, window signal 4; F, guard  
 20 interval signal; G, valid signal delayed by 1 symbol; and H, IDFT signal after addition of a guard interval.

The OFDM transmission/reception apparatus of the present embodiment selects one of window signals with different high-level interval lengths and finds the  
 25 logical product of the window signal and the valid symbol. In this way, the OFDM transmission/reception apparatus of the present embodiment can set the same number of guard interval lengths as the number of window signals.

For example, the guard interval signal shown at F is generated as follows. That is, the OFDM transmission/reception apparatus of the present embodiment calculates the logical product of the valid symbol shown at A and window signal 3 shown at D to extract the symbol with the same length as the high-level interval of window signal 3 shown at D from the last part of valid symbol A. In this way, the guard interval signal shown at F is generated.

As shown above, the OFDM transmission/reception apparatus of the present embodiment selects a window signal with a different high-level interval length every time an optimal guard interval length detection signal inserted into a transmission signal is received. Then, the OFDM transmission/reception apparatus of the present embodiment calculates the logical product of the selected window signal and valid symbol to generate a guard interval according to the channel quality. In this way, the OFDM transmission/reception apparatus of the present embodiment can expand/contract a guard interval length according to the channel quality.

Then, the operation of the reception system of the OFDM transmission/reception apparatus of the present embodiment is explained using FIG.5.

The reception signal input to the reception system is converted to a digital signal by A/D converter 107.

The OFDM transmission/reception apparatus of the present embodiment calculates a correlation between a

pre-DFT signal and the pre-DFT signal delayed by a valid symbol length. The OFDM transmission/reception apparatus of the present embodiment detects the integration interval of DFT by detecting the timing at which the correlation result becomes largest. More specifically, delayer 108 delays the reception signal by the valid symbol length, then correlator 109 calculates a correlation and timing generator 110 detects the timing at which the correlation result becomes largest. Guard interval eliminator 111 eliminates the guard interval from the reception signal according to this detection result.

The reception signal stripped of the guard interval is DFT-processed by DFT circuit 112. This results in 4 baseband signals, which are carried by 4 carriers. The 4 baseband signals are subjected to coherent detection by coherent detectors 113 to 116, respectively. In this way, coherent detected signals are obtained. Here, a delay detection system can also be used as the demodulation system.

The coherent detected signals obtained by coherent detectors 113 to 116 are judged by Deciders 117 to 120. The 4 signals judged by Deciders 117 to 120 are converted to a serial signal by P/S converter 124. In this way, a demodulated signal is obtained.

On the other hand, switch 121 selects only the optimal guard interval length selection control signal from the output signal of Decider 120 and outputs it to

guard interval inserter 105.

Subtractor 122 carries out a subtraction between the signal input to Decider 117 and the signal output from Decider 117 to calculate the decision error. Here, this decision error is determined as the channel quality. Optimal guard interval length detector 123 generates an optimal guard interval length selection control signal using the decision error calculated by subtractor 122, that is, channel quality information.

Here, the optimal guard interval length detector of the OFDM transmission/reception apparatus of the present embodiment is explained using FIG.8. FIG.8 is a block diagram showing an outlined configuration of the optimal guard interval length detector of the OFDM transmission/reception apparatus of the present embodiment.

The decision error input to optimal guard interval length detector 123 is selectively output by switch 401 and S/P-converted by S/P converter 402.

Subtractor 403 calculates a subtraction between the first output of S/P converter 402 and the second output of S/P converter 402. Likewise, subtractor 404 calculates a subtraction between the first output and the third output, and subtractor 405 calculates a subtraction between the first output and the fourth output.

In this way, optimal guard interval length detector 123 finds a difference between the decision error of the

symbol indicating the longest guard interval length (here, decision error of the symbol indicating "symbol period/2" which is the first output of S/P converter 402) and the decision error of another symbol.

5        Furthermore, subtractor 406 calculates a subtraction between the output of subtractor 403 and a threshold. Likewise, subtractor 407 calculates a subtraction between the output of subtractor 404 and the threshold, and subtractor 408 calculates a subtraction  
10        between the output of subtractor 405 and the threshold. Then, Deciders 409 to 411 judge the outputs of subtractors 406 to 408.

As shown above, decision errors are compared with thresholds. Then, guard interval inserter 105 inserts  
15        the guard interval with the shortest guard interval of the guard intervals indicated by the symbols producing decision errors less than the threshold into the transmission signal.

That is, Deciders 409 to 411 output a high level  
20        (1, for example) in the case that the decision error is not less than the threshold (that is, the channel quality is good) and output a low level (0, for example) in the case that the decision error is less than the threshold. Then, the outputs of Deciders 409 to 411 are P/S-  
25        converted by P/S converter 412 to become an optimal guard interval length selection control signal. This optimal guard interval length selection control signal is included in the transmission signal and transmitted.

The received optimal guard interval length selection control signal is S/P-converted to control signals for switches 202 to 204 by S/P converter 201. That is, the outputs of Deciders 409 to 411 become control  
5 signals for switches 202 to 204. The guard interval insertion procedure hereafter is as already described.

As shown above, the OFDM transmission/reception apparatus of the present embodiment detects the reception condition of each symbol of an optimal guard  
10 interval length detection signal and decides up to which of the 4 symbols have been received. This allows the OFDM transmission/reception apparatus of the present embodiment to detect the minimum necessary guard interval length to eliminate delayed signals, making it  
15 possible to change the guard interval to an appropriate length suitably.

The length of a guard interval to be added to each symbol should be longer than the maximum delay time of a delayed signal assumed in an environment in which the  
20 OFDM transmission/reception apparatus of the present embodiment is used. However, such a delayed signal with the maximum delay time assumed does not always exist. Therefore, as described above, the OFDM transmission/reception apparatus of the present  
25 embodiment can improve the transmission efficiency without deteriorating the error rate characteristic by adaptively changing the length of guard intervals to prevent any guard interval that is longer than required.



from being provided.

As shown above, the OFDM transmission/reception apparatus of the present embodiment can improve the transmission efficiency by adaptively changing the  
5 length of guard intervals.

The present embodiment is explained assuming that the number of carriers is 4, but the number of carriers can be increased to 8, 16, 32, and 64, and so on with an apparatus configuration similar to the configuration  
10 above.

In the present embodiment, the types of window signals are not limited to the 4 types above, but any number of window signals with a predetermined high-level intervals can be set.

15 Furthermore, in the present embodiment, FFT (Fast Fourier Transform) and IFFT (Inverse Fast Fourier Transform) can also be used instead of DFT and IDFT. Similar effects can be achieved in such cases, too.

20 (Embodiment 2)

The OFDM transmission/reception apparatus of Embodiment 2 of the present invention has the same configuration as that of the OFDM transmission/reception apparatus of Embodiment 1 and uses symbols of optimal  
25 guard interval length detection signals of a plurality of bursts.

The optimal guard interval length detector of the OFDM transmission/reception apparatus of the present

embodiment is explained below using FIG.9. FIG.9 is a block diagram showing an outlined configuration of the optimal guard interval length detector of the OFDM transmission/reception apparatus of Embodiment 2 of the present invention. The parts with the same configuration as that of Embodiment 1 are assigned the same numbers and their detailed explanations are omitted.

Averagers 501 to 503 perform averaging on the outputs of subtractors 403 to 405.

In this way, the optimal guard interval length detector performs averaging using symbols of optimal guard interval length detection signals of a plurality of bursts. Therefore, the OFDM transmission/reception apparatus of the present embodiment can achieve higher accuracy of an optimal guard interval length selection control signal than that of the OFDM transmission/reception apparatus of Embodiment 1.

(Embodiment 3)

The OFDM transmission/reception apparatus of Embodiment 3 of the present invention has the same configuration as that of the OFDM transmission/reception apparatus of Embodiment 1 and inserts symbols for optimal guard interval length detection signals into a plurality of carriers.

The optimal guard interval length detector of the OFDM transmission/reception apparatus of the present

embodiment is explained below using FIG. 10. FIG. 10 is a block diagram showing an outlined configuration of the optimal guard interval length detector of the OFDM transmission/reception apparatus of Embodiment 3 of the present invention. The parts with the same configuration as that of Embodiment 1 are assigned the same numbers and their detailed explanations are omitted.

The transmission system of the OFDM transmission/reception apparatus of the present embodiment has switch 601. With switch 601, an optimal guard interval length detection signal is inserted into not only carrier 1 but also carrier 2.

Furthermore, the reception system of the OFDM transmission/reception apparatus of the present embodiment also has subtractor 602 and Averager 603. Subtractor 602 calculates the decision error of carrier 2. Averager 603 calculates the average of decision errors of carrier 1 and carrier 2. Averager 603 outputs the average value of the decision errors to optimal guard interval length detector 123.

As shown above, the OFDM transmission/reception apparatus of the present embodiment inserts an optimal guard interval length detection signal into a plurality of carriers and generates an optimal guard interval length selection control signal using the average value of decision errors. This allows the OFDM transmission/reception apparatus of the present

embodiment to achieve higher accuracy of optimal guard interval length selection control signal than that of the OFDM transmission/reception apparatuses of Embodiments 1 and 2.

5

(Embodiment 4)

The OFDM transmission/reception apparatus of Embodiment 4 of the present invention has the same configuration as that of the OFDM transmission/reception apparatus of Embodiment 3, but does not average optimal guard interval length detection signals before they are input to the optimal guard interval length detector and performs a logical product calculation on the optimal guard interval length detection signals using the optimal guard interval length detector.

The optimal guard interval length detector of the OFDM transmission/reception apparatus of the present embodiment is explained below using FIG. 11 and FIG.12. FIG.11 is a block diagram showing an outlined configuration of the OFDM transmission/reception apparatus of Embodiment 4 of the present invention. FIG.12 is a block diagram showing an outlined configuration of the optimal guard interval length detector of the OFDM transmission/reception apparatus of Embodiment 4 of the present invention. The parts with the same configuration as that of Embodiments 1 and 3 are assigned the same numbers and their detailed explanations are omitted.

As shown in FIG.11, the OFDM transmission/reception apparatus of the present embodiment does not average the decision errors of carrier 1 and carrier 2, and inputs the decision errors of carrier 1 and carrier 2 to optimal guard interval length detector 701.

Then, as shown in FIG.12, logical product calculators 801 to 803 perform a logical product calculation on the outputs of Deciders 409 to 411 for carrier 1 and the outputs of Deciders 409 to 411 for carrier 2.

As shown above, the OFDM transmission/reception apparatus of the present embodiment can achieve higher accuracy of an optimal guard interval length selection control signal by selecting a guard interval length whose difference between decision errors falls below a threshold as the optimal guard interval length in all carriers into which symbols for optimal guard interval detection have been inserted.

(Embodiment 5)

The OFDM transmission/reception apparatus of Embodiment 5 of the present invention has the same configuration as that of the OFDM transmission/reception apparatus of Embodiment 3 but does not use carriers whose reception level falls below a threshold to detect the optimal guard interval length.

The optimal guard interval length detector of the

OFDM transmission/reception apparatus of the present embodiment is explained below using FIG.13.

FIG.13 is a block diagram showing an outlined configuration of the OFDM transmission/reception

5 apparatus of Embodiment 5 of the present invention. The parts with the same configuration as that of Embodiments 1 and 3 are assigned the same numbers and their detailed explanations are omitted.

Square sum calculator 901 calculates the sum of  
10 squares of coherent detected signals of carrier 1.

Square sum calculator 902 calculates the sum of squares of coherent detected signals of carrier 2.

Then, subtractor 903 carries out a subtraction between the output of square sum calculator 901 and a  
15 threshold and Decider 905 decides which is larger/smaller based on the subtraction result.

Subtractor 904 carries out a subtraction between the output of square sum calculator 902 and the threshold and Decider 906 decides which is larger/smaller based  
20 on the subtraction result.

Switches 907 and 908 are controlled by Deciders 905 and 906, respectively. In the case that the reception levels of their respective carriers (that is, the outputs of square sum calculators 901 and 902) are less than the  
25 threshold, switches 907 and 908 do not output the decision errors of the carriers to Averager 603.

As shown above, based on the fact that the reception levels vary for each carrier in a frequency selection

fading environment, the OFDM transmission/reception apparatus of the present embodiment assumes that the carrier whose reception level falls below the threshold does not have good channel quality and does not use the carrier whose reception level falls below the threshold for detection of the optimal guard interval length. This allows the OFDM transmission/reception apparatus of the present embodiment to achieve higher accuracy of optimal guard interval length selection control signals.

10

(Embodiment 6)

The OFDM transmission/reception apparatus of Embodiment 6 of the present invention has the same configuration as that of the OFDM transmission/reception apparatus of Embodiment 5 and has a level detector with a simple configuration instead of the square sum calculator.

The present embodiment describes a case where the input signal is a QPSK-modulated signal and the known reference signal is a pilot symbol.

The level detector of the present embodiment finds envelope information from the absolute values of the I component and Q component by approximate calculation and detects the reception level.

Envelope information  $Z$  can be obtained from  $Z = \sqrt{(|I|^2 + |Q|^2)}$ . However, obtaining a square sum from  $\sqrt{(|I|^2 + |Q|^2)}$  requires a relatively great amount of calculation. Therefore, to reduce the amount of

calculation to a minimum, it is possible to find a square sum by approximate calculation using approximate expression  $Z = |I| + |Q|$ . However, in the case that this approximate expression is used, the square sum becomes  
 5 a maximum (when phase is  $45^\circ$ ) of 1.414 times the value calculate by  $\sqrt{(|I|^2 + |Q|^2)}$ . That is, an error of a maximum of approximately 41% will result, deteriorating the error rate characteristic.

Therefore, the OFDM transmission/reception  
 10 apparatus of the present embodiment uses an approximate expression using a simple multiplication by a bit shift. That is, the OFDM transmission/reception apparatus of the present embodiment uses  $Z = |I| + 0.375 \times |Q|$  when  $|I| > |Q|$  and  $Z = |Q| + 0.375 \times |I|$  when  $|Q| > |I|$  as an  
 15 approximate expression.

FIG.14 is a graph showing the result of a theoretical calculation of the relationship between phase  $\theta$  and estimated radius (that is amplitude) when  $|I| > |Q|$  (that is, range of  $0 \leq \theta \leq 45^\circ$ ). From this graph,  
 20 it is clearly seen that using the above approximate expression makes it possible to obtain envelope information with an error within 7% of the case obtained with a square sum.

Then, the level detector of the OFDM  
 25 transmission/reception apparatus of the present embodiment obtains envelope information using the above approximate expression and detects the reception level.

The level detector of the OFDM



transmission/reception apparatus of the present embodiment is explained using FIG.15. FIG.15 is a block diagram showing an outlined configuration of the level detector of the OFDM transmission/reception apparatus of Embodiment 6.

The I component and Q component of one carrier after coherent detection processing are input to absolute value detectors 1101 and 1102. Absolute value detectors 1101 and 1102 calculate the absolute values of input signals and outputs the absolute values to subtractor 1105 and adder 1110. The I component or Q component is selected by switches 1103 and 1104. The subtraction result from subtractor 1105 is judged by Decider 1106. The decision results are used to control switches 1103 and 1104.

2-bit shifter 1107 and 3-bit shifter 1108 shift the output of switch 1104 by 2 bits and 3 bits, respectively. The outputs of 2-bit shifter 1107 and 3-bit shifter 1108 are added up by adder 1109. This allows multiplication processing of 0.375 in the above approximate expression to be performed. Adder 1110 adds up the output of switch 1103 and the output of adder 1109 and outputs envelope information.

Then, the operation of the level detector of the OFDM transmission/reception apparatus of the present embodiment is explained.

The absolute values of the I component and Q component are calculated by absolute value detectors

1101 and 1102, respectively. In this way, absolute values  $|I|$  and  $|Q|$  are obtained.

Then, subtractor 1105 performs a subtraction between the outputs of absolute value detectors 1101 and 1102 ( $|I|$  and  $|Q|$ ). Decider 1106 decides which is larger/smaller based on the subtraction result. The outputs of absolute value detectors 1101 and 1102 ( $|I|$  and  $|Q|$ ) are selected by switches 1103 and 1104, respectively and output. Switches 1103 and 1104 select the signal to be output according to the decision result of Decider 1106.

When the output of Decider 1106 indicates  $|I| > |Q|$ , switch 1103 outputs  $|I|$ . When the output of Decider 1106 indicates  $|Q| > |I|$ , switch 1103 outputs  $|Q|$ . Furthermore, when the output of Decider 1106 indicates  $|I| > |Q|$ , switch 1104 outputs  $|Q|$ . When the output of Decider 1106 indicates  $|Q| > |I|$ , switch 1104 outputs  $|I|$ . In short, switch 1103 outputs  $|I|$  or  $|Q|$ , whichever is greater and switch 1104 outputs  $|I|$  or  $|Q|$ , whichever is smaller.

The smaller one of  $|I|$  or  $|Q|$  output from switch 1104 is shifted by 2 bits and 3 bits by 2-bit shifter 1107 and 3-bit shifter 1108, respectively.

Since a 1-bit shift reduces the amplitude to half, the amplitude becomes 0.25 times with a 2-bit shift and 0.125 times with a 3-bit shift. Therefore, the amplitude of the output signal of 2-bit shifter 1107 becomes 0.25 times the amplitude of the output signal of switch 1104.

The amplitude of the output signal of 3-bit shifter 1108 becomes 0.125 times the amplitude of the output signal of switch 1104.

Then, adder 1109 adds up the output signal of 2-bit shifter 1107 ( $0.25 \times |I|$  or  $0.25 \times |Q|$ ) and the output signal of 3-bit shifter 1108 ( $0.125 \times |I|$  or  $0.125 \times |Q|$ ). Therefore, the output signal of adder 1109 becomes  $0.375 \times |I|$  or  $0.375 \times |Q|$ .

Then, adder 1110 adds up the output signal of switch 1103 ( $|I|$  or  $|Q|$ ) and the output signal of adder 1109 ( $0.375 \times |I|$  or  $0.375 \times |Q|$ ). From this, envelope information Z is obtained from the approximate expression above.

As shown above, the level detector of the OFDM transmission/reception apparatus of the present embodiment detects the reception level by finding an envelope, and thus it does not perform a multiplication unlike the square sum calculator of Embodiment 5. Therefore, the OFDM transmission/reception apparatus of the present embodiment has a simpler configuration, making it possible to reduce the necessary amount of calculation.

Moreover, the OFDM transmission/reception apparatus of the present embodiment can further reduce the necessary amount of calculation in calculating an envelope by using an approximate expression only consisting of simple multiplications and additions, which can be implemented by bit shifts on the circuit.

The present embodiment describes the case where the input signal is a QPSK-modulated signal. However, the above apparatus configuration is also applicable to any other cases where other modulation systems are used so long as the input signal can be separated into the I component and Q component.

(Embodiment 7)

The OFDM transmission/reception apparatus of Embodiment 7 of the present invention has the same configuration as that of the OFDM transmission/reception apparatus of Embodiment 1 and uses a known symbol as the optimal guard interval length detection signal.

The OFDM transmission/reception apparatus of the present embodiment is explained below using FIG.16. FIG.16 is a block diagram showing an outlined configuration of the OFDM transmission/reception apparatus of Embodiment 7 of the present invention. The parts with the same configuration as that of Embodiment 1 are assigned the same numbers and their detailed explanations are omitted.

As shown in FIG.16, the OFDM transmission/reception apparatus of the present embodiment uses a known symbol as the optimal guard interval length detection signal. Subtractor 1201 performs a subtraction between the carrier 1 signal prior to its input to Decider 117 and a known symbol and outputs the difference between these two to optimal guard

interval length detector 123.

Thus, the OFDM transmission/reception apparatus of the present embodiment uses a known symbol as the optimal guard interval length detection signal, therefore can  
5 improve the accuracy of the optimal guard interval length selection control signal.

(Embodiment 8)

The OFDM transmission/reception apparatus of  
10 Embodiment 8 of the present invention has the same configuration as that of the OFDM transmission/reception apparatus of Embodiment 1 and uses a variable threshold to be used in the optimal guard interval length detector.

The OFDM transmission/reception apparatus of the  
15 present embodiment is explained below using FIG.17. FIG.17 is a block diagram showing an outlined configuration of the optimal guard interval length detector of the OFDM transmission/reception apparatus of Embodiment 8 of the present invention. The parts with  
20 the same configuration as that of Embodiment 1 are assigned the same numbers and their detailed explanations are omitted.

Switch 1301 selects an input decision error and outputs it to S/P converter 402 and Averager 1302. The  
25 previous burst channel quality information is stored in memory 1304 by the switching of switch 1303.

The channel quality information stored in memory 1304 is subjected to a subtraction with threshold A by

subtractor 1305. Decider 1306 decides which is larger/smaller based on the subtraction result. Switch 1307 is controlled by the decision result of Decider 1306 and outputs either threshold B or threshold C. Here,  
5 suppose threshold B > threshold C.

As shown above, considering the possibility that if, for example, the channel quality is bad, variations in the decision error will increase and a longer guard interval length than the optimal guard interval length  
10 will be selected, the OFDM transmission/reception apparatus of the present embodiment can improve the accuracy of the optimal guard interval length selection control signal by changing the threshold to a greater value in the case that the decision error information  
15 stored in memory exceeds the threshold.

(Embodiment 9)

The OFDM transmission/reception apparatus of Embodiment 9 of the present invention has the same  
20 configuration as that of the OFDM transmission/reception apparatus of Embodiment 1, and selects a guard interval length in which a difference between decision errors falls below a threshold in a plurality of bursts as the optimal guard interval length.

25 The OFDM transmission/reception apparatus of the present embodiment is explained below using FIG.18. FIG.18 is a block diagram showing an outlined configuration of the optimal guard interval length

detector of the OFDM transmission/reception apparatus of Embodiment 9 of the present invention. The parts with the same configuration as that of Embodiment 1 are assigned the same numbers and their detailed  
5 explanations are omitted.

In FIG.18, counters 1401 to 1403 output the outputs of Deciders 409 to 411 for every a plurality of bursts. Subtractors 1404 to 1406 perform a subtraction between the outputs of counters 1401 to 1403 and a threshold.  
10 Deciders 1407 to 1409 decide which is larger/smaller based on the subtraction results.

Thus, the OFDM transmission/reception apparatus of the present embodiment selects a guard interval length in which a difference between decision errors falls below  
15 a threshold in a plurality of bursts as the optimal guard interval length, thus improving the accuracy of the optimal guard interval length selection control signal.

(Embodiment 10)

20 The OFDM transmission/reception apparatus of Embodiment 10 of the present invention has the same configuration as that of the OFDM transmission/reception apparatus of Embodiment 1, and sets the maximum guard interval length in the case that the channel quality of  
25 the carrier into which an optimal guard interval length selection control signal is inserted falls below a threshold.

The OFDM transmission/reception apparatus of the

present embodiment is explained below using FIG.19. FIG.19 is a block diagram showing an outlined configuration of the OFDM transmission/reception apparatus of Embodiment 9 of the present invention. The parts with the same configuration as that of Embodiment 1 are assigned the same numbers and their detailed explanations are omitted.

In FIG.19, subtractor 1501 performs a subtraction on the carrier into which an optimal guard interval length selection control signal is inserted (here carrier 4) between the signal before being input to Decider 120 and the output signal from Decider 120. That is, subtractor 1501 calculates a decision error of carrier 4.

Then, the decision error of carrier 4 is averaged by Averager 1502. Subtractor 1503 performs a subtraction between the averaged decision error and a threshold. Decider 1504 decides which is larger/smaller based on the subtraction result. Switch 1505 is controlled by the decision result of Decider 1504 and selects either the output of optimal guard interval length detector 123 or the control signal indicating the maximum guard interval and outputs it to switch 103.

Thus, the OFDM transmission/reception apparatus of the present embodiment sets the maximum guard interval length in the case that the channel quality of the carrier into which an optimal guard interval length selection control signal is inserted falls below a



threshold. Thus, in the case that an error exists in the optimal guard interval length selection control signal after demodulation, the OFDM

transmission/reception apparatus of the present  
5 embodiment can prevent the optimal guard interval length from failing to be set, and thus prevent the error rate characteristic from deteriorating.

By the way, the OFDM transmission/reception  
apparatus of the present embodiment can also achieve the  
10 same effect as that described above in the case that it performs error detection on the carrier into which the optimal guard interval length selection control signal is inserted and set the maximum guard interval length when an error is detected.

15

(Embodiment 11)

The OFDM transmission/reception apparatus of  
Embodiment 11 of the present invention has the same  
configuration as that of the OFDM transmission/reception  
20 apparatus of Embodiment 1, and eliminates the need for transmission/reception of a control signal about the guard interval length by transmitting a signal using the optimal guard interval length detected from a reception signal in both radio stations carrying out a radio  
25 communication.

The OFDM transmission/reception apparatus of the  
present embodiment is explained below using FIG.20.

FIG.20 is a block diagram showing an outlined

configuration of the OFDM transmission/reception apparatus of Embodiment 11 of the present invention. The parts with the same configuration as that of Embodiment 1 are assigned the same numbers and their detailed  
5 explanations are omitted.

The present embodiment describes a case where a radio communication is carried out using a OFDM/TDD system.

In FIG. 20, optimal guard interval length detector  
10 1601 outputs a control signal about the guard interval length to guard interval inserter 105.

In a TDD system, a same frequency is used for the uplink and downlink, and therefore the channel information is identical for the uplink and downlink.  
15 Therefore, the OFDM transmission/reception apparatus of the present embodiment can eliminate the need for transmission/reception of the optimal guard interval length selection control signal by transmitting a signal using the optimal guard interval length detected from  
20 the reception signal in both radio stations carrying out a radio communication.

In the case that the OFDM transmission/reception apparatus of the present embodiment uses the optimal guard interval length selection control signal, the OFDM  
25 transmission/reception apparatus of the present embodiment can also detect the optimal guard interval length even if an error exists in the optimal guard interval length selection control signal after

demodulation. Thus, the OFDM transmission/reception apparatus of the present embodiment can prevent the error rate characteristic of the control signal from deteriorating.

5

(Embodiment 12)

The OFDM transmission/reception apparatus of Embodiment 12 of the present invention has the same configuration as that of the OFDM transmission/reception  
10 apparatus of Embodiment 11, and detects the optimal guard interval length using a control channel signal.

The OFDM transmission/reception apparatus of the present embodiment is explained below using FIG.21. FIG.21 is a block diagram showing an outlined  
15 configuration of the OFDM transmission/reception apparatus of Embodiment 12 of the present invention. The parts with the same configuration as that of Embodiment 11 are assigned the same numbers and their detailed explanations are omitted.

20 In FIG.21, switches 1701 and 1702 are controlled by a control channel signal whose error is corrected more strongly than the user channel signal. That is, the control channel signal controls the timing of inserting an optimal guard interval length detection signal in the  
25 transmission system and the timing of extracting an optimal guard interval length detection signal in the reception system.

As shown above, the OFDM transmission/reception

apparatus of the present embodiment detects the guard interval length using a control channel signal, and therefore can reduce the probability that an error will occur in the control signal that the optimal guard interval length detector outputs.

(Embodiment 13)

The OFDM transmission/reception apparatus of Embodiment 13 of the present invention has the same configuration as that of the OFDM transmission/reception apparatus of Embodiment 1, and controls the selection of the guard interval length to be added to a valid symbol using a known signal (Unique Word; hereinafter referred to as "UW") to acquire synchronization of a plurality of frames.

The OFDM transmission/reception apparatus of the present embodiment is explained below using FIG.22 and FIG.23. FIG.22 is a block diagram showing an outlined configuration of the OFDM transmission/reception apparatus of Embodiment 13 of the present invention. FIG.23 is a block diagram showing an outlined configuration of a UW detector of the OFDM transmission/reception apparatus of Embodiment 13 of the present invention. The parts with the same configuration as that of Embodiment 1 are assigned the same numbers and their detailed explanations are omitted.

In FIG.22, the output of optimal guard interval

length detector 123 controls switch 1801. One of UW1 to UW4 is selected by switch 1801 according to this control and output to switch 103.

Here, in the case that the decision error of UW1 is bad, UW1 indicates that a guard interval length of "symbol period/2" is necessary. Likewise, UW2 indicates that a guard interval length of " $3 \times$  symbol period/8" is necessary; UW3, guard interval length of "symbol period/4"; and UW4, guard interval length of "symbol period/8."

UW detector 1802 detects UW in the demodulated reception signal. The detected UW is selectively output to guard interval inserter 105 by switch 1803.

Generally, in frame synchronization acquisition using UW, an exclusive OR calculation between UW and a demodulated signal is performed. In the case that the accumulated value of the results of the exclusive OR calculations exceeds a threshold, it is determined that frame synchronization has been acquired. Here, even if errors exist in the UW after demodulation in the case that the number of those errors is within the range that the accumulated value of the exclusive OR calculation results exceeds a threshold, frame synchronization is correctly acquired.

In FIG.23, exclusive OR calculators 1901 to 1904 perform exclusive OR calculations between the demodulated signal input to UW detector 1802 and each of UW1 to UW4. Subtractors 1905 to 1908 perform

subtractions between the outputs of exclusive OR calculators 1901 to 1904 and a threshold.

Deciders 1909 to 1912 judge the outputs of subtractors 1905 to 1908. Then P/S converter 1913  
5 converts 4 parallel decision data to single serial data.

Logical sum calculator 1914 performs a logical sum calculation of the outputs of subtractors 1905 to 1908. Switch 1915 is controlled by the output of logical sum calculator 1914 and selectively outputs the output of  
10 P/S converter 1913.

As shown above, the OFDM transmission/reception apparatus of the present embodiment acquires frame synchronization using a plurality of UWs and controls the selection of a guard interval length according to  
15 the information on which UW has acquired frame synchronization. This allows the OFDM transmission/reception apparatus of the present embodiment to reduce the probability that an error will exist in the guard interval length selection control  
20 signal and thus prevent the error rate characteristic from deteriorating.

By the way, the OFDM transmission/reception apparatus of the present embodiment is especially valid for an OFDM system other than TDD.

25

(Embodiment 14)

The OFDM transmission/reception apparatus of Embodiment 14 of the present invention has the same

configuration as that of the OFDM transmission/reception apparatus of Embodiment 13, and reduces the number of UWs used by the UW detector.

The UW detector of the OFDM transmission/reception apparatus of the present embodiment is explained below using FIG.24. FIG.24 is a block diagram showing an outlined configuration of the UW detector of the OFDM transmission/reception apparatus of Embodiment 14 of the present invention. The parts with the same configuration as that of Embodiment 13 are assigned the same numbers and their detailed explanations are omitted.

In FIG.24, exclusive OR calculator 2001 performs an exclusive OR calculation of the demodulated signal and UW1. Exclusive OR calculator 2001 outputs the result of the exclusive OR calculation of the demodulated signal and UW1 to subtractor 2003. Exclusive OR calculator 2001 also outputs the result of the exclusive OR calculation of the demodulated signal and the inverted signal of UW1 to subtractor 2004. Likewise, exclusive OR calculator 2002 performs an exclusive OR calculation of the demodulated signal and UW2. Exclusive OR calculator 2002 outputs the result of the exclusive OR calculation of the demodulated signal and UW2 to subtractor 2005. Exclusive OR calculator 2002 also outputs the result of the exclusive OR calculation of the demodulated signal and the inverted signal of UW2 to subtractor 2006.

Here, in the case that the decision error of UW1

is large, UW1 indicates that a guard interval length of "symbol period/2" is necessary. Likewise, the inverted signal of UW1 indicates a guard interval length of "3 × symbol period/8" is necessary; UW2, a guard interval  
 5 length of "symbol period/4"; and the inverted signal of UW2, a guard interval length of "symbol period/8."

As shown above, the OFDM transmission/reception apparatus of the present embodiment can reduce to half the number of exclusive OR calculations carried out by  
 10 the UW detector by using the inverted signal of UW. This reduces the amount of calculation and simplifies the circuit configuration.

(Embodiment 15)

15 The OFDM transmission/reception apparatus of Embodiment 15 of the present invention has the same configuration as that of the OFDM transmission/reception apparatus of Embodiment 13, and carries out UW detection using a demodulated signal prior to decision processing.

20 The OFDM transmission/reception apparatus of the present embodiment is explained below using FIG.25 and FIG.26. FIG.25 is a block diagram showing an outlined configuration of the OFDM transmission/reception apparatus of Embodiment 15 of the present invention.

25 FIG.26 is a block diagram showing an outlined configuration of a UW detector of the OFDM transmission/reception apparatus of Embodiment 15 of the present invention. The parts with the same



configuration as that of Embodiment 13 are assigned the same numbers and their detailed explanations are omitted.

As shown in FIG.25, synchronization detection  
5 signals before being input to Deciders 117 to 120 are input to UW detector 2101.

Furthermore, as shown in FIG.26, the demodulated signals input to UW detector 2101 are converted to a serial signal by P/S converter 2201. Multipliers 2202  
10 to 2205 multiply the output signal of P/S converter 2201 by UW1 to UW4, respectively.

As shown above, the OFDM transmission/reception apparatus of the present embodiment acquires frame synchronization using coherent detected signals prior  
15 to decision processing, and thus can reduce the probability that an error will occur in a control signal.

(Embodiment 16)

The OFDM transmission/reception apparatus of  
20 Embodiment 16 of the present invention has the same configuration as that of the OFDM transmission/reception apparatus of Embodiment 13, and uses a variable threshold in UW detectors according to decision errors.

The OFDM transmission/reception apparatus of the  
25 present embodiment is explained below using FIG.27 and FIG.28. FIG.27 is a block diagram showing an outlined configuration of the OFDM transmission/reception apparatus of Embodiment 16 of the present invention.

FIG.28 is a block diagram showing an outlined configuration of the UW detector of the OFDM transmission/reception apparatus of Embodiment 16 of the present invention. The parts with the same configuration as that of Embodiment 13 are assigned the same numbers and their detailed explanations are omitted.

As shown in FIG.27, the decision error of carrier 1, which is the output of subtractor 122, together with a demodulated signal is input to UW detector 2301. The decision error need not always be from carrier 1.

Furthermore, as shown in FIG.28, subtractor 2401 performs a subtraction between the decision error input to UW detector 2301 and threshold A. Then, Decider 2402 decides which is larger/smaller based on the subtraction result. Switch 2403 is controlled by the output of Decider 2402. Switch 2403 outputs threshold B in the case that the decision error is not less than the threshold and outputs threshold C in the case that the decision error is less than the threshold. Here, suppose threshold B > threshold C.

As shown above, the OFDM transmission/reception apparatus of the present embodiment uses a variable threshold used to acquire frame synchronization in the UW detectors according to the channel quality. That is, the OFDM transmission/reception apparatus of the present embodiment decreases the threshold when the channel quality is bad. This allows the OFDM

transmission/reception apparatus of the present embodiment to improve the accuracy of frame synchronization acquisition. Moreover, in the case that the channel quality is bad, the OFDM

5 transmission/reception apparatus of the present embodiment can also improve the accuracy of frame synchronization acquisition by reducing the threshold using the channel quality information of the previous burst (for example, decision error).

10

(Embodiment 17)

The OFDM transmission/reception apparatus of Embodiment 17 of the present invention has the same configuration as that of the OFDM transmission/reception  
15 apparatus of Embodiment 13, and in the case that the decision error in the UW detector exceeds a threshold, it controls in such a way that the guard interval length is maintained.

The OFDM transmission/reception apparatus of the  
20 present embodiment is explained below using FIG.29. FIG.29 is a block diagram showing an outlined configuration of the UW detector of the OFDM transmission/reception apparatus of Embodiment 17 of the present invention. The parts with the same  
25 configuration as that of Embodiments 13 and 16 are assigned the same numbers and their detailed explanations are omitted.

In FIG.29, switch 2501 is controlled by the output .

of Decider 2402. Switch 2501 selects either the output of switch 1915 or a zero value and outputs it.

As shown above, in the case that the channel quality is bad in the UW detector, the OFDM transmission/reception apparatus of the present embodiment outputs a zero value to maintain the guard interval length without changing the threshold for acquisition of frame synchronization. Therefore, the OFDM transmission/reception apparatus of the present embodiment can prevent the error rate characteristic from deteriorating or frame synchronization from failing to be acquired, a situation which is likely to occur when a threshold is changed with a bad channel quality.

15 (Embodiment 18)

The OFDM transmission/reception apparatus of Embodiment 18 of the present invention has the same configuration as that of the OFDM transmission/reception apparatus of Embodiment 1, and does not change the length of a guard interval to be added to a valid symbol indicating important information, but always keeps it constant independently of the channel quality.

The "guard interval length necessary to eliminate delayed signal" described so far in Embodiments 1 to 17 has been the length apparently enough to achieve an error rate in a communication related to user data such as a message (hereinafter referred to as "normal information"). However, higher accuracy is required

for important information such as control information and retransmission information than normal information in terms of the error rate.

Thus, the OFDM transmission/reception apparatus of the present embodiment distinguishes important information from normal information in a transmission signal and does not change the length of a guard interval to be added to the valid symbol indicating important information according to the channel quality, but always keeps it constant.

The OFDM transmission/reception apparatus of the present embodiment sets the guard interval length to be added to the valid symbol indicating the important information above to a certain length that allows an error rate lower than the error rate achieved by the guard interval to be added to the valid symbol indicating normal information.

The OFDM transmission/reception apparatus of the present embodiment is explained below using FIG.30 to FIG.32. FIG.30 is a block diagram showing an outlined configuration of the OFDM transmission/reception apparatus of Embodiment 18 of the present invention. FIG.31 is a timing chart showing an example of the step of the guard interval inserter of the OFDM transmission/reception apparatus of Embodiment 18 of the present invention adding a guard interval. FIG.32 is a timing chart showing an example of the step of the guard interval eliminator of the OFDM transmission/reception

apparatus of Embodiment 18 of the present invention eliminating a guard interval. The parts with the same configuration as that of Embodiment 1 are assigned the same numbers and their detailed explanations are omitted.

In FIG.30, a known timing control signal is input to guard interval inserter 2601. Therefore, guard interval inserter 2601 can distinguish a symbol indicating normal information from another symbol indicating important information in the transmission symbol based on this timing.

As described above, guard interval inserter 2601 changes the length of a guard interval to be added to a valid symbol according to the channel quality. However, based on the decision result above, guard interval inserter 2601 sets the length of the guard interval to be added to the valid symbol indicating important information to a predetermined fixed value independently of the channel quality. On the other hand, in the case of the valid symbol indicating normal information, guard interval inserter 2601 sets a guard interval length according to the channel quality using the method described in Embodiment 1.

FIG.31 shows an example of the step of the guard interval inserter of the OFDM transmission/reception apparatus of the present embodiment adding a guard interval. As shown in the chart, a longer guard interval is added to the valid symbol indicating important

information than the guard interval added to the valid symbol indicating normal information.

FIG.32 shows an example of the step of guard interval eliminator 111 of the OFDM

5 transmission/reception apparatus of the present embodiment eliminating a guard interval. Guard interval eliminator 111 is informed of the timings of starting the guard interval and starting the valid symbol. Therefore, guard interval eliminator 111 can extract  
10 only valid symbols and eliminate guard intervals through normal processing even if the guard interval length in the valid symbol indicating normal information and the valid symbol indicating important information changes.

As shown above, the OFDM transmission/reception  
15 apparatus of the present embodiment distinguishes important information from normal information in a transmission signal and sets the length of a guard interval to be added to the valid symbol indicating the important information to a predetermined value that  
20 implements an error rate lower than the error rate about the normal information independently of the channel quality. Through this, the OFDM transmission/reception apparatus of the present embodiment can change the length of a guard interval to be added to the valid symbol  
25 indicating the normal information thereby improving the transmission efficiency, while it can set a lower error rate for important information than for normal information. Thus, the OFDM transmission/reception

apparatus of the present embodiment can improve the channel quality and transmission efficiency.

(Embodiment 19)

5       The OFDM transmission/reception apparatus of Embodiment 19 of the present invention has the same configuration as that of the OFDM transmission/reception apparatus of Embodiment 18, and always adds to the valid symbol indicating important information a guard interval  
10 longer by a certain length than the guard interval to be added to the valid symbol indicating normal information.

      Since the OFDM transmission/reception apparatus of Embodiment 18 always adds a certain length of guard  
15 interval to the valid symbol indicating important information, in the case that the error rate is low and the channel quality is high, a longer guard interval than is necessary is added.

      Thus, in the guard interval length setting in the  
20 present embodiment, the OFDM transmission/reception apparatus sets the length of the guard interval to be added to the valid symbol indicating important information to the length of the guard interval to be added to the valid symbol indicating normal information  
25 according to the channel quality plus a predetermined constant value.

      In this way, the OFDM transmission/reception apparatus of the present embodiment distinguishes



important information from normal information in the transmission signal and always sets the length of the guard interval to be added to the valid symbol indicating important information longer than the guard interval to be added to the valid symbol indicating normal information by a predetermined constant value. Through this, the OFDM transmission/reception apparatus of the present embodiment can change the length of a guard interval to be added to the valid symbol indicating normal information thereby improving the transmission efficiency, while it can set a lower error rate for important information than for normal information. Thus, the OFDM transmission/reception apparatus of the present embodiment can improve the channel quality and transmission efficiency.

(Embodiment 20)

The OFDM transmission/reception apparatus of Embodiment 20 of the present invention has the same configuration as that of the OFDM transmission/reception apparatus of Embodiment 19, and adds to the valid symbol indicating important information a guard interval longer by a predetermined value determined according to the channel quality than the guard interval to be added to the valid symbol indicating normal information.

The OFDM transmission/reception apparatus of Embodiment 19 of the present invention always adds to the valid symbol indicating important information a

guard interval consisting of the guard interval added to the valid symbol indicating normal information according to the channel quality plus a predetermined constant length. Therefore, under a condition with a high error rate and poor channel quality, there may be cases where it is impossible to improve the error rate of important information by predetermined percentage compared to the error rate of normal information.

Therefore, in the guard interval length setting of the present embodiment, the OFDM transmission/reception apparatus sets the length of the guard interval to be added to the valid symbol indicating important information to the length of the guard interval to be added to the valid symbol indicating normal information according to the channel quality plus a predetermined length proportional to the channel quality.

That is, as the channel quality improves and the error rate decreases, the OFDM transmission/reception apparatus of the present embodiment shortens the predetermined value added to the length of the guard interval to be added to the valid symbol indicating normal information, and to the contrary as the channel quality deteriorates and the error rate increases, the OFDM transmission/reception apparatus of the present embodiment lengthens the predetermined value added to the length of the guard interval to be added to the valid symbol indicating normal information.

As shown above, the OFDM transmission/reception

apparatus of the present embodiment distinguishes important information from normal information in the transmission signal and sets the length of the guard interval to be added to the valid symbol indicating important information longer than the guard interval to be added to the valid symbol indicating normal information by a predetermined variable length according to the channel quality. Through this, the OFDM transmission/reception apparatus of the present embodiment can change the length of a guard interval to be added to the valid symbol indicating normal information thereby improving the transmission efficiency, while it can set a lower error rate for important information than for normal information. Thus, the OFDM transmission/reception apparatus of the present embodiment can improve the channel quality and transmission efficiency.

Here, in contrast to the configuration of the OFDM transmission/reception apparatus of Embodiments 1 to 17 with a variable guard interval length, the configuration of the OFDM transmission/reception apparatus of Embodiments 18 to 20 above distinguishes important information from normal information in the transmission signal and sets the guard interval length as follows:

- 1) For normal information: variable according to channel quality; for important information: constant
- 2) For normal information: variable according to channel quality; for important information: constant

difference from the one "for normal information"

3) For normal information: variable; for  
important information: difference from the one "for  
normal information" is variable according to channel  
5 quality

These are intended to keep the error rate of  
important information lower than the error rate of normal  
information, and the OFDM transmission/reception  
apparatus can take any configuration other than the above  
10 3 configurations so long as it can achieve these  
purposes.

Embodiments 18 to 20 above are Embodiment 1 with  
the additional function to improve the error rate about  
important information. In like manner, it is also  
15 possible to add the additional function to improve the  
error rate about important information to Embodiments  
2 to 17 by combining Embodiments 18 to 20 above with  
Embodiments 2 to 17.

Embodiments 18 to 20 above can improve the error  
20 rate not only about important information but also about  
specific information and packet (burst). Embodiments  
18 to 20 above can have a longer guard interval than other  
information or packet (burst) in the case of multicast,  
for example.

25 As explained above, the present invention is  
capable of improving transmission efficiency while  
maintaining the function of adding guard intervals and  
eliminating delayed signals.

The present invention is not limited to the above described embodiments, and various variations and modifications may be possible without departing from the scope of the present invention.

5        This application is based on the Japanese Patent Application No.HEI 10-365430 filed on December 22, 1998 and the Japanese Patent Application No.HEI 11-074621 filed on March 18, 1999, entire content of which is expressly incorporated by reference herein.